Renewable and Sustainable Energy Reviews 15 (2011) 1669–1674

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Development of grid connection requirements for wind power generators in India

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ARTICLE INFO

Article history:
Received 15 March 2010
Accepted 10 November 2010
Available online 22 January 2011

Keywords:
Grid connection requirements
Operational issues
Remuneration of wind power
Wind power

ABSTRACT

Grid integration is one of the major concerns in recent years as wind power generation level keeps on increasing continuously in the power system. Therefore, wind farms will have a significant influence on the operation and control of emerging power system, which is expanding in terms of interconnections, network capacity, load demand and addition of new devices for improving the performance of the system. New grid codes are being set up in several countries by specifying the relevant requirements for efficient, stable and secure operation of power system and these specifications have to be met in order to integrate wind power into the modern electric grid. Several states of India have high penetration of wind power and specific grid connection requirements (GCR) for wind power are yet to be established. This paper proposes GCR for wind power integration in India and discusses several technical and operational issues arising due to high penetration of wind power generation in Indian power systems.

Contents

1. Introduction

During the last decade, the installed capacity of wind power generation has been increased tremendously all over the world and expected to grow in future too due to environmental, economic and energy security issues. Wind is an innovative, clean, modular, and intermittent technology. Increased penetration of wind power into the electricity grid gives rise to new challenges for the entire system and, in particular, to the transmission system operators in maintaining reliability and stability of electricity supply. Although available wind forecasting techniques are suitable and accurate up to some extent but these tech-

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doi:10.1016/j.rser.2010.11.026

niques are not satisfactory especially in the competitive electricity markets.

In the past, grid connection requirement (GCR) for wind power generators or wind farms was not necessary due to low level of wind power penetration. IEEE Standard 1001 '*IEEE Guide for Interfacing Dispersed Storage and Generation Facilities with Electric Utility Systems*' was the only guideline for the connection of generation facilities to the distribution networks. The standard included the basic issues of power quality, equipment protection and safety. The standard expired and, therefore, in 1998, the IEEE Working Group SCC21 P1547, the *IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems* started to work on a general recommendation for the interconnection of distributed generation [1].

The interconnection rules are continuously reformulated because of the increasing wind power penetration in to the grid and the rapid development of wind power generation system technology. The main focus in the electricity grid codes has been on the fault ride-through issue, where the TSO requires wind power generators to stay connected to the grid during and after a fault in the transmission system. Another important requirement to the wind power installations is on active and reactive power control capability, to make the wind power installations able to support the control of grid frequency and grid voltage. In the several countries, new grid codes are already in place for the wind power integration and these specifications have to be met [2].

Wind power program in India is the highly successful and occupies the fifth position in the world having wind power installed capacity of 11 GW as on January 2010. However, the percentage of wind power generation is very small due heavy generation from other sources of energy. Indian Government policy and regulatory framework both at the state and central levels are encouraging power generation from new and renewable energy sources. This sector has been growing at over 35% in the last 4 years. The wind power program in India was initiated towards the end of the Sixth Plan (1983–1984) and aims at catalyzing commercialization of wind power generation in the country [3,4]. In India, with increasing penetration of wind energy, share of wind power as percentage of installed generation capacity has exceeded 10% in many states, however, the common specific grid connection standards for wind power are yet to be established. Technical guidelines and requirements for wind power generation are varying with one state to other states and not good enough for the large wind power integration into the grid. In order to promote wind power and to maintain common grid discipline there is an urgent need of a specific and common grid code for wind power integration in India. In this work a common grid code requirements have been suggested and some technical and operational issues of high penetration of wind power for Indian power system are addressed.

2. Proposed grid codes of wind power in India

The Indian electricity grid code for wind farms (IEGCWF) proposed in this section outlines the minimum technical grid connection requirements that new wind turbines and associate systems at the connection point to the transmission network have to provide safe and reliability operation of the system [5]. The new connection shall not cause any adverse effect to the electric grid which shall continue to perform with specified reliability, security, and quality as per the central electricity authority (CEA) regulations, as and when they come into force. These developments must clearly indicate the need to search for effective solutions to alleviate the negative impacts, if any, of the large scale integration of wind power to the grid so that the benefit of the renewable energy source can be maximized.

IEGCWF must be read in conjunction with

(a) Indian electricity grid code (IEGC) issued by central electricity regulatory commission CERC [6],
(b) Technical standards for connectivity to the grid, Regulations 2007, issued by CEA [7], and
(c) State electricity grid codes issued by respective states of India (in this work, Rajasthan state electricity grid code (REGC) is referred [8]).

The full capabilities of wind farms may not be exploited at all times. Therefore, the connection codes should be such that it should provide the maximum power output from the wind farm without affecting the existing grid operation. The following aspects are taken into consideration for large-scale grid integration of wind power in India:

- Active power control,
- Reactive power control,
- Fault ride through capability,
- Communication requirements,
- Others (modeling and validation, power quality, start and stop, metering etc.).

2.1. Active power control

The wind power generating units are normally operated to maximum power using maximum power point tracking algorithm and remain connected to the network even if the system frequency deviates from specified one. Active (real) power control is used to control the system frequency by changing the power injected into the grid. The active power production from the wind farm must be controllable to maintain the security and stability of the electric grid. The following control functions must be available.

- An adjustable upper limit to the active power production from the wind farm shall be available whenever the wind farm is in operation. The upper limit control of active power production, measured as a 15-min average value, does not exceed a specified level and the limit shall be adjustable by remote signals. It must be possible to set the limit to any value with an accuracy of ±5%, in the range from 20% to 100% of the wind farm rated power.
- Ramping control of active power production must be possible to limit the ramping speed of active power production from the wind turbine in upwards direction (increased production due to increased wind speed or due to changed maximum power output limit) to 10% of rated power per minute. There is no requirement to down ramping due to fast wind speed decays, but it must be possible to limit the down ramping speed to 10% of rated power per minute, when the maximum power output limit is reduced by a control action.
- Fast down regulation should be possible to regulate the active power from the wind turbine down from 100% to 20% of rated power in less than 5 s. This functionality is required for system protection schemes. Some system protection schemes implemented for stability purposes require the active power to be restored within short time after the down regulation. For that reason, disconnection of a number of wind turbines cannot be used to fulfill this requirement.
- Automatic control of the wind turbine active production as a function of the system frequency must be possible. The control function must be proportional to the frequency deviations with a dead-band. The detailed settings can be provided by the state utilities (SU).

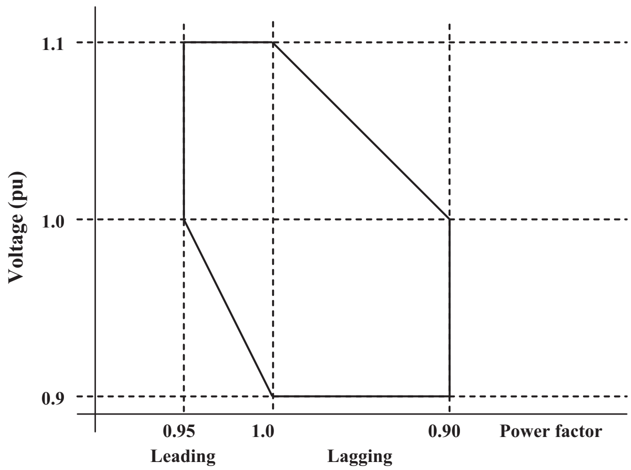

Fig. 1. Operating range of power with voltage.

Table 1
Grid voltage operating limits.

Nominal system voltage	Grid voltage Variation limits	Maximum	Minimum
400 kV	+5%/−10%	420 kV	360 kV
220 kV	+/−10%	245 kV	200 kV
132 kV	+/−10%	145 kV	120 kV
33 kV	+/−10%	36 kV	30 kV

- During under-frequency (it shows the deficit in the generation), wind power can increase the power output without affecting the network congestion.

In India, the system frequency has controlled by the state load dispatch centers (SLDC) in coordination with regional load dispatch centers (RLDC) at about 50 Hz, within the range of 49.2–50.3 Hz band [9]. Wind farms must be capable of operating continuously for 49.2–50.3 Hz frequency band and allowed to be disconnected during over frequency as per the wind turbine specifications. In addition, the wind turbines can reduce power at frequency of above 50.3 Hz as detailed settings provided by the SU.

2.2. Reactive power control

The reactive power control requirement is used for generating units to supply lagging/leading reactive power at the grid connection point. Wind farms should be capable of supplying a proportion of the system's reactive capacity, including the dynamic capability and should contribute to maintain the voltage profile by providing reactive power support. Requirements of the grid codes for reactive power support that the power factor is to be maintained in the specified range. Wind farms are required to balance voltage deviations at the connection point by adjusting their reactive power exchange and, moreover, by setting up predetermined power factors. Wind farms shall be capable of operating at rated output for power factor varying between 0.9 lagging (over-excited) to 0.95 leading (under-excited). Fig. 1 shows the operating range of wind farms at different voltage levels. The above performance shall also be achieved with voltage variation of ±10% of nominal, frequency variation of +1.6% and −0.06% and combined voltage and frequency variation of ±10%. Wind farms are required to have sufficient reactive power compensation to be neutral in reactive power at any operating point. In India the SLDC (and users), ensure that the grid voltage remains within the operating limits as specified in IEGC 5.2, as show in Table 1, and hence it is required from the wind turbine to remain connected and deliver power for the specified voltage ranges and put efforts to maintain it.

Also, wind farms shall make available the up-to-date capability curves indicating restrictions to the SLDC/RLDC, to allow accurate system studies and effective operation of the state transmission system. The reactive power output of the wind farm must be controllable in one of the two following control modes according to SU specifications.

- The wind farm shall be able to control the reactive exchange with the system at all active power production levels. The control shall operate automatically and on a continuous basis.
- The wind farm must be able to automatically control its reactive power output as a function of the voltage at the connection point for the purpose of controlling the voltage.

The detailed settings of the reactive power control system will be provided by the respective SU. The wind farm must have adequate reactive power capacity to be able to operate with zero reactive exchange with the network measured at the connection point, when the voltage and the frequency are within normal operation limits.

2.3. Fault-ride through capability

Fault-ride through (FRT) requirement is imposed on a wind power generator so that it remains stable and connected to the network during the network faults. Disconnection from grid may worsen the situation and can threaten the security standards at high wind penetration. The wind farm must be able to operate satisfactorily during and after the disturbances in the distribution/transmission network. This requirement applies under the following conditions:

- The wind farm and the wind turbines in the wind farm must be able to stay connected to the system and to maintain operation during and after clearing faults in the distribution/transmission system.
- The wind farm may be disconnected temporarily from the system, if the voltage at the connection point during or after a system disturbance falls below the certain levels.

The fault, where the voltage at the connection point may be zero, duration is 100 ms for 400 kV and 160 ms for 220 kV and 132 kV. Wind turbines are required to be equipped with under-frequency and over-frequency protection, under-voltage and over-voltage protection, differential protection of the generator transformer, and backup protection (including generator over-current protection, voltage-controlled generator over-current protection, or generator distance protection). Prevalent practice shall be followed according to Regulations 2007.

2.4. Communication requirements

Wind farms must be controllable from remote locations by telecommunication system. Supervisory control and data acquisition (SCADA) is recommended for the remote control of wind power and telemetry of the important parameters for scheduling and forecasting is obtained. Control functions and operational measurements must be made available to the SLDC/RLDC. The SU in each area specifies the required measurements and other necessary information to be transmitted from the wind farm. Information required generally from wind farms are voltage, current, frequency, active power, reactive power, operating status, wind speed, wind direction, regulation capability, ambient temperature and pressure, frequency control status and external control possibilities.

Reliable and efficient communication systems shall be provided to facilitate necessary communication and data exchange, and supervision/control of the grid by the SLDC/RLDC, under normal and abnormal conditions, as specified in Regulation 2007.

2.5. Other requirements

Metering

Recording instruments such as data acquisition system/disturbance recorder/event logger/fault locator (including time synchronization equipment) shall be installed at each wind farms for recording of dynamic performance of the system. Agencies shall provide all the requisite recording instruments as specified in the connection agreement according to the agreed time schedule. These requirements are similar for conventional power sources and mentioned in detail in CEA (Installation and operation of meters, Regulation 2006) [10], IEGC, and respective state electricity grid codes.

Start and stop

It is recommended, that the wind farms be designed so that the wind turbine does not stop simultaneously within the wind farm due to high wind speeds.

Modeling and validation

Prior to the installation of a wind turbine or a wind farm, a specific test programme must be agreed with the SU in the area regarding the capability of the wind turbine or wind farm to meet the requirements in this connection code. As a part of the test programme, a simulation model of the wind turbine or wind farm must be provided to the SU in a given format and the model shall show the characteristics of the wind turbine or wind farm in both static simulations (load flow) and dynamic simulations (time simulations). The model shall be used in feasibility studies prior to the installation of the wind turbine or wind farm and the commissioning tests for the wind turbine or the wind farm shall include a verification of the model. These requirements are similar to the conventional power sources and mentioned in detail in IEGC and respective state electricity grid codes.

Power quality

Prevalent practice shall be followed according to IEGC, state grid codes and International standards like IEEE and IEC [11,12].

3. Indian power sector reforms: policy support for grid interactive renewable power

Electricity Act 2003

Section 86. (1). The state commission shall discharge the following functions... (e): promote cogeneration and generation of electricity from renewable sources of energy by providing suitable measures for connectivity with the grid and sale of electricity to any person, and also specify, for purchase of electricity from such sources, a percentage of the total consumption of electricity in the area of a distribution licensee [4].

National electricity policy 2005

The national electricity policy 2005 stipulates that progressively the share of electricity from non-conventional sources would need to be increased; such purchase by distribution companies shall be through competitive bidding process; considering the fact that it will take some time before non-conventional technologies compete, in terms of cost, with conventional sources, the commission may determine an appropriate deferential in prices to promote these technologies.

Tariff Policy 2006

The tariff policy announced in January 2006 has the following provisions:

- Pursuant to provisions of Section 86 (1) (e) of the Act, the appropriate commission shall fix a minimum percentage for purchase of energy from such sources taking into account the availability of such resources in the region and its impact on retail tariffs. Such percentages of energy purchase should be made applicable for the tariffs to be determined by the state electricity regulatory commission (SERCs) latest by April 01, 2006.
- It will take some time before non-conventional technologies can compete with conventional sources in terms of cost of electricity. Therefore, the procurement by distribution companies shall be done at preferential tariffs determined by the appropriate commission.
- Such procurement by distribution licensees for future requirements shall be done, as far as possible, through competitive bidding process under Section 63 of the Act within suppliers offering energy from the same type of non-conventional sources. In the long-term, renewable energy technologies based power generation would need to compete with other sources in terms of full costs.
- The central commission should lay down guidelines within 3 months for pricing non-firm power, especially from non-conventional sources, to be followed in cases where such procurement is not through competitive bidding.

4. Grid connectivity and evacuation arrangements

Grid connectivity has posed a major challenge in harnessing the renewable energy as most of the renewable energy sources, particularly wind and small hydro sites are in remote areas wherein transmission and distribution network is sparse. As per the provisions of Electricity Act 2003, it is the responsibility of concerned licensee or respective state utility (SU) to provide grid connectivity to the generating stations. However, due to various reasons, there have been difficulties for developing the infrastructure for evacuation of energy generated from renewable energy sources. Further, Electricity Act 2003 under Section 86(1) (e) specifically empowers state electricity regulatory commission (SERC) to take suitable measures for ensuring the grid connectivity to the renewable energy projects or wind farms. However in most of the cases, responsibility of licensee and wind farm developer in developing the evacuation infrastructure varies across the states.

In most of the states, *inter connection point* stretches up to nearest grid sub-station and associated cost for development of such evacuation infrastructure is required to be borne by the wind farm developer. *Inter connection point* can be defined as an interface point to the transmission or distribution network, to which the wind turbine or wind farm is to be connected. For wind energy projects, *inter connection point* is to be located and specified by the respective SU. General connectivity conditions elaborated in Regulations 2007 must be held valid for wind farms.

Therefore, it is preferred that evacuation infrastructure from generator terminal up to grid *inter connection point* shall be developed by the wind farm developer and beyond *inter connection point* the concerned licensee shall develop the network. The concerned licensee or SU shall be responsible for providing grid connectivity to the wind farms from the *inter connection point*, on payment of wheeling or transmission charges as the case may be, in accordance with the regulations of the respective SERC.

Table 2
Preferential tariffs/policy introduced announced by the SERC's for wind.

Sources, states	Wind power, items		
	Wheeling charges	Banking	Buy-back (INR/kWh)
Andhra Pradesh	2% of energy	12 months	3.37
Gujarat	4% of energy	–	3.37 fixed for 20 years
Haryana	2% of energy	Allowed	4.08 + Escalation 1.5%
Karnataka	2% of energy	2%/month for 12 months	3.40 fixed for 10 years
Kerala	5% of energy	9 months (June–February)	3.14 fixed for 20 years
Maharashtra	2% of energy +5% trans. loss	12 months	3.50 + Escalation of 0.15 for 13 years from documentation of the project
Madhya Pradesh	2% of energy	Not allowed	3.97 (with decrease of 0.7 up to 4th year) then fixed at 3.30 from 5th year onwards uniformly for 20 years
Rajasthan	10% of energy	3 months	3.59 for Jaisalmer, Jodhpur, etc. and 3.67 for other districts
Tamil Nadu	5% of energy	5%, 12 months	2.90 (levelised)
West Bengal	INR 0.3/kWh	6 months	To be decided on case to case with a cap of 4

5. Remuneration for wind power

The national tariff policy, which was notified by the Ministry of Power in January 2006, in continuation with the Electricity Act 2003 and the National Electricity Policy 2005, emphasizes the importance of setting renewable energy targets and preferential feed-in tariffs for renewable energy procurement by the respective SERC. Several SERC, in turn, provided details on concessional feed-in tariffs (mostly decided by *cost-based approach*), wheeling (transporting electric power over transmission lines), banking of energy for future use, third party sale and power evacuation facilities, as shown in Table 2 with other fiscal incentive, as shown in Table 3 [3]. Recently, CERC issues regulations of terms and conditions for tariff determination from renewable energy sources, Regulations 2009 which is single part tariff consisting of the following fixed cost components [13]:

- Return on equity;
- Interest on loan capital;
- Depreciation;
- Interest on working capital;
- Operation and maintenance expenses.

Table 3
Implemented fiscal incentives for wind power generation.

Item	Description
Accelerated depreciation	80% depreciation in the first year can be claimed for the following equipment: for wind: extra 20% after March 2005 for new plant and machinery
Tax holiday	Ten years tax holidays
Customs duty	Concessional customs and excise duty exemption for machinery and components for initial setting up of projects
Sales tax	Exemption is available in certain states

It also considers the incentive or subsidy offered by the central/state government to the renewable energy power plants while determining the tariff under these Regulations. Wind power is fed into the grid when and where available on priority basis and these shall be treated as *must run* power plants and shall not be subjected to 'merit order dispatch' principles in order to maximize generation and in order to gainfully utilize wind power already installed. Recently government of India announces generation based incentives (GBI) schemes for new wind farms. Under this scheme, a GBI will be provided to wind electricity producers Rs. 0.50 per unit of electricity fed into the grid for a period not less than 4 years and a maximum period of 10 years in parallel with fiscal incentives such as accelerated depreciation on a mutually exclusive manner, with a cap of Rs. 62 lakhs per MW [4].

Reactive power from wind farms must be remunerated according to IEGC 6.6, presented as follows [6]. Reactive power compensation should ideally be provided locally, by generating reactive power as close to the reactive power consumption as possible. The beneficiaries (means the person purchasing electricity generated at the generating station) are therefore expected to provide local VAr compensation/generation such that they do not draw VArs from the extra high voltage (EHV) grid, particularly under low-voltage condition. However, considering the present limitations, this is not being insisted upon. Instead, to discourage VAr drawals by beneficiaries, VAr exchanges with inter-state transmission system (ISTS) shall be priced as follows.

- The beneficiary pays for VAr drawal when voltage at the connection point is below 97%.
- The beneficiary gets paid for VAr return when voltage is below 97%.
- The beneficiary gets paid for VAr drawal when voltage is above 103%.
- The beneficiary pays for VAr return when voltage is above 103%.

Provided that there shall be no charge/payment for VAr drawl/return by a beneficiary on its own line emanating directly from an inter-state generating system (ISGS).

6. Operational issues

With increasing penetration of wind power, it is equally important to address concerns of grid operations. In case, information about likely wind power generation forecast is available then, it will facilitate grid operation. Internationally, such information about wind energy generation forecast is available through sophisticated software and extensive data analysis and simulation techniques [11]. Accordingly, authors suggest for Indian system that in near future it should be made mandatory for all non-firm renewable energy generating sources (RES), especially wind power, shall furnish the tentative day-ahead hourly generation forecast (MWh) for the energy availability at *inter connection point* to the concerned RLDC/SLDC to facilitate better grid co-ordination and management. Also with the provisions to update and correct forecast it by hour-ahead forecast to minimize the real time scheduling error. Further, it has been clarified that above forecasts shall be used for calculating deviation from such scheduled forecasts and must be subjected to unscheduled interchange (UI) mechanism outlined under CERC UI Regulations 2009, but with suitably selected price cap on wind power generation decided in conjunction with fixed price paid for wind power. The argument for putting such ceiling for wind

power generators is that cost of energy generation through wind is lower than the ceiling price specified by the CERC and it was considered that there is sufficient incentive for the wind power generator even with a low ceiling price and more important to prevent any gaming. Wind farm owners are in-charge of balancing his own production balance by market-based means or by developing technical capabilities. Unscheduled interchange mechanism is a best mechanism, exercised in India, can make wind power (or other non-firm renewable energy sources) semi-competitively dispatchable. In this proposed manner, wind farm owners continually get fixed return on wind power they accurately dispatched and get paid/charges for UI power. Wind farm owners can optimally schedule their generation slightly lower than actually forecasted wind power to avoid any charges. Sufficient return on wind power will ensure promotion to wind power in longer term and UI mechanism will ensure the competiveness and technological innovation. As there is huge demand–supply gap prevails in India, frequency remains mostly in lower side of range specified for UI mechanism and hence remunerate much more, for UI injection of power, compare to fixed price received by wind power in next future.

7. Interconnection regulations harmonisation

Several states of India have high penetration of wind power and it is expected that this share will increase with time. Present scenario can be observed that the interconnection regulations vary considerably from state to state. Harmonized technical GCR are required and it will bring the maximum efficiency for all parties and should be employed wherever it is possible and appropriate. While this applies for all generation technologies, there is a particular urgency in the case of wind power. As wind penetration is forecasted to increase significantly in the short to medium term, it is essential that grid code harmonization process is to be done immediately. It will help the manufacturers to internationalize their products/services, the developers to reduce the cost and the system operators to share experience, mutually, in operating power systems.

It can be stated that GCR should be harmonized at least in the areas those have little impact on the overall costs of wind turbines. In other areas, GCR should take into account the specific power system robustness, the penetration level and/or the generation technology. The technical harmonization in the following areas is recommended [2]

- Wind power farm behaviour in normal network conditions.
- Behaviour during and after network disturbances.
- Frequency response/active power control.
- Voltage control/reactive power.
- Verification and testing.
- Site-related aspects.

Harmonization in GCR will help in achieving following goals:

- For setting of proper regulations for the connection of wind power technology to the electricity grid;
- For facilitating the internationalization of manufacturers and developers; and
- For developing new standards, codes and verification procedures, interaction between GCR issuing working groups.

8. Conclusions

Wind farms have a significant influence on the operation of power systems. Grid codes are set up to specify the relevant requirements for efficient and secure operation of power system for all network users and these specifications have to be met in order to integrate wind turbines into the grid. Several states of India have high penetration of wind power and it is expected that this share will increase with time. The Indian electricity grid code for wind farms (IEGCWF) has been proposed in this work which outlines the minimum technical grid connection requirements that new wind turbines together with their supplemental installations have to fulfill at the connection point to the transmission network in order to provide for adequate safe operation and reliability of the interconnected Indian power system. Several technical and operational issues with increased wind power penetration has discussed for emerging Indian power systems.

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